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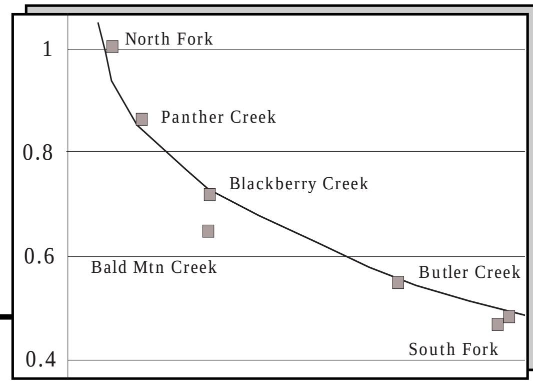

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Use of Basin Survey Data in Habitat Modelling and Cumulative Watershed Effects Analyses

Glenn K. Chen
Siskiyou National Forest
Powers Ranger District
Powers, Oregon 97466
(503) 439-3011; R06F11D05A

Introduction

Basin-wide stream survey methodologies have been adopted by numerous agencies in recent years. For fisheries biologists, these inventories have proved to be an invaluable resource for managing stream fish populations and their habitat. The techniques focus on using statistical sampling methods to gather quantitative data on both biological and geomorphic stream characteristics. Storage of data on PC-computer databases allow access to powerful software packages which facilitate data analysis.

The basin inventory method of Hankin and Reeves (1988) is widely utilized in the western states and has been incorporated into a number of standardized procedures. This method was first tested on the Elk River, a Pacific Northwest coastal watershed located in the vicinity of Port Orford, Oregon (southwest Oregon). Since 1985, approximately 70 miles of the Elk have been surveyed annually by researchers from the USDA Forest Service Pacific Northwest Experiment Station, under the direction of Dr. Gordon Reeves. Results from these efforts have clearly demonstrated the importance of scale in stream survey methodology. Reeves documented the variable nature of salmonid production and habitat characteristics related to processes operating on channel unit, reach, sub-basin, and watershed scales.

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Biologists are now focusing their attention on the applications of basin inventories. The Siskiyou National Forest has made extensive use of the Elk River data to address a number of management needs. The Elk was recently granted National Wild and Scenic River status, and the fisheries information from these surveys were key in its designation, and have proven to be invaluable for the river resource assessment and management plan. Other uses include the development of an empirical model linking habitat features and fish abundance. This relationship has been further utilized as a quantitative tool to assess the cumulative effects on fish habitat from logging activities in the basin. The following paper discusses the processes used in both habitat modeling and watershed effects assessment.

Several noteworthy events have occurred since the development of the Elk River cumulative effects analysis. The Elk Fork Timber Sale, encompassing the North Fork Elk River basin (a designated Wild River and one of the most productive salmonid areas in the watershed) was offered for auction in fall of 1990. Seven lawsuits which focused on protecting fisheries values in the North Fork were subsequently filed, and much of the controversy centered around the implementation of the watershed effects analysis. As a result, a review of the analysis process was requested by Siskiyou National Forest and Regional Office staff. In summary, the reviewers found that the sediment model and the fish habitat model were acceptable, but the portion of the analysis linking sediment and fish needed further evaluation before it could be used to guide management decisions. This prompted the withdrawal of the sale by the Regional Forester and a subsequent decision by management staff to discontinue use of the sediment/fish correlation. Continuing interest in the effects analysis by fisheries and watershed resources specialists, however, merit its inclusion in this paper.

Habitat and Fish Relationships

Analysis Using Basin Survey Data

The relationship of habitat to fish is a key concept in the management of fisheries. However, we have often operated with scant knowledge of the specific interactions between habitat characteristics and stream fish populations. The survey methods that were previously employed were part of the problem, since they usually provided data with limited resolution capabilities. Collected information was primarily descriptive in nature, with an emphasis on reach summaries and the use of broad categorical classifications; important small-scale features were often not quantified. Efforts were concentrated on short segments that were considered to be “representative” of the entire stream. Estimation of fish populations relied on electroshocking or streamside observation, further limiting the data’s interpretive value.

The realization of these shortcomings led to the development of new survey techniques. In methods such as Hankin/Reeves, individual channel units comprise the primary level of organization. Each unit is classified into a particular habitat type, and quantitative data is collected on its physical attributes. At systematic intervals, fish abundance is determined. The key link here is that fish numbers are paired with specific physical habitat information on a unit-by-unit basis. The use of estimation reduces data collection time and enables the expansion of survey efforts to include entire basins. Periodic measurements are added to evaluate the statistical accuracy of these estimates. The utilization of PC computer databases allows for direct exportation to analysis software packages. Data in a quantitative format, and with the assistance of microcomputers, enables the biologist to develop empirical models that can yield a better understanding of the factors contributing to fish production within a watershed.

An Example from Elk River

Winter steelhead trout are common to many Pacific Northwest coastal watersheds. Part of their anadromous life history involves extended rearing in freshwater stream environments. Two juvenile age classes are found in coastal streams: young-of-the-year fry, referred to as 0+ juvenile steelhead; and yearling parr, or 1+ steelhead. Because adult steelhead support valuable sport fisheries, many habitat projects are directed towards the needs of juvenile steelhead. Yearling steelhead are often the focus because their abundance is considered to be limiting to adult production. An understanding of how specific habitat features contribute to increased numbers of 1+ steelhead can be obtained from basin survey data.

The portions of the Elk River basin within the Siskiyou National Forest support approximately 95% of all steelhead production in the basin. An examination of the basin survey data revealed that the North Fork Elk River has the greatest densities of yearling steelhead. The North Fork basin has experienced little impact from timber harvest or associated roading. Because of its productivity and lack of management-related influences, the data from the North Fork was used to construct a yearling steelhead habitat model for the Elk River watershed.

Data for the North Fork consisted of the following:

1) Two miles of stream habitat categorized into four types of units (pool, riffles, glides, and side channels), from 1986 and 1987. The two miles encompass the total section of stream inhabited by anadromous salmonids.

2) Quantitative physical data for each habitat type:

   a. Estimated length
   b. Estimated width
   c. From length and width, unit area
   d. Mean depth
   e. From length, width, mean depth, unit volume
   f. Dominant substrate (8 numerical classes representing silt to large boulders, similar to phi classes)
   g. Large wood in the unit (6 classes of wood based on size and configuration). Wood data were used to derive a “wood index” for each unit, representing a measure of volume, configuration, and structural complexity.
   h. Channel constraint (derived from ratio of valley bottom:channel width). This was collected at the reach scale and applied to all units within the reach.

3) Quantitative fish data for each habitat type at systematic intervals (numbers of salmonids by species and/or age class)

Comparisons between the different habitat types indicated that pools supported the highest numbers of 1+ steelhead. A total of twenty-two pools had been sampled for fish and these units comprised the data set from which the model was derived.

Model development was performed using a PC computer. The data were transferred from Lotus 1-2-3 spreadsheets into STATGRAPHICS, a statistical analysis software program. The desired output was to produce a statistical model which mathematically-related various habitat features to the numbers of yearling steelhead in pool habitat of the North Fork Elk River. The model would be in the form of a multiple regression equation, with habitat parameters as the independent variables, and 1+ steelhead numbers as the dependent variable. STATGRAPHICS was selected because of its simple menu format and added graphics capabilities.

To construct the yearling steelhead model, a number of statistical procedures were utilized. A correlation analysis was performed between each of the physical habitat variables and the numbers of yearling steelhead for all pools sampled. This produced a table of coefficients that allowed identification of correlated variables for use in the regression.

In addition to the table, a "draftsmans plot" was created. This is a STATGRAPHICS function which produces a matrix of scatter plots that allows one to visually verify these correlations. Such examination is useful, because "significant" coefficient values can be falsely obtained due to the presence of a small subset of non-representative data points; the draftmans plot enables the user to quickly identify such spurious correlations. It also permits the user to see if inter-correlation exists between the predictor variables. This allows one to use combinations of independent variables to further refine the regression model.

From the correlation table, the list of variables was narrowed down to **channel constraint**. An examination of the draftmans plot and the table showed that **wood debris** and **mean depth** were inter-correlated predictor variables. In regression analysis these can be tested as multiplicative variables. Thus, **wood x depth** was added to **constraint** as possible choices for the steelhead habitat model.

The third procedure involved the use of multiple regression in STATGRAPHICS. The two variables were combined using stepwise regression. Stepwise techniques sequentially add predictors based on F-tests for significance. Intercept and coefficients are then calculated, producing a multiple regression equation. Further tests on the regression were performed (eg, residual plots). The influence of outlier points was also evaluated. After adjusting the model as needed using these criteria, more regression iterations were run. The final model was then tested for significance.

Using stepwise regression, STATGRAPHICS selected **constraint** and **wood x depth** variables for inclusion in the final model (p was set at < 0.05 for the F-tests). Two outliers were removed either because of their disproportionate influence on the regression, or because they were outside the scatter of points. This reduced the sample size from 22 to 20. No adjustment of the linear model was found necessary in the residual plots. The final equation is stated below:

#s of 1+ steelhead + -4.501 + 3.396 (constraint) + 12.752 (wood*depth)

Standard errors for coefficients were 1.273 (s.e. B_1) and 1.999 (s.e. B_2). The final regression model met statistical criteria for significance ($F_{2,18} = 62.74$, corresponding to a $p < 0.05$; R-square = 0.861).

For pools in the North Fork, this analysis documents that greater numbers of yearling steelhead are correlated with a combination of wider valley floor areas and increased depth created by wood material. To verify the basin-wide applicability of the model, we conducted similar analyses for all tributaries in Elk River. Pool depth, wood, and wider valley floor areas turned out to be key elements for yearling steelhead in other parts of the basin as well.

The ability of the habitat model to predict fish numbers suggests that it can also be used for estimating population levels. Typically, such estimates have relied upon the extrapolation of average density calculations, with the assumption that the relationship between surface area and fish numbers is constant. However, this is often not the case. Very large, deep pools have disproportionately lower densities than small pools because much of the area is not utilized by fish. Surface area is two-dimensional, but fish clearly respond to features in other dimensions, such as depth. Basin variability in fish densities are often due to changes in reach characteristics, rather than differences in spatial area. Other features not directly associated with habitat area (such as wood debris) may also have an influence on the number of fish present. Such sources of variation affect mean density calculations and subsequent population estimates derived from them. Use of a regression model, rather than density extrapolations, may result in more accurate determinations of stream fish populations.

Comparisons of population estimates based on area/density extrapolation versus the values calculated from the habitat regression model are given in Table 1.

	Habitat Model Prediction	Density Extrapolation	Actual Fish Numbers
	7	12	3
	3	10	4
	7	5	5
	6	8	7
	20	18	19
	21	25	18
	14	15	19
	19	32	21
	42	25	32
	33	26	36
	30	23	37
	34	26	41
Totals:	237	225	241

Table 1. North Fork Elk River. Results from steelhead habitat model, density extrapolation, and actual numbers of yearling steelhead in 16 sampled pools. (Actual fish numbers derived from snorkeling visual counts. Density extrapolation based upon mean density of 0.1385 1+ sthd/m^2, N = 16.)

Activity Impact Assessments:

Evaluation of Fish Habitat Conditions & Use in Cumulative Effects Analysis

The previous section discusses how basin survey data were used to develop a fish habitat model. This model was a key element in the analysis of cumulative watershed effects for the Elk River basin.

Cumulative effects, as opposed to direct effects, involve expanded spatial and temporal scales for analysis. Although numerous definitions exist of what constitute "cumulative effects", a definition used in the National Environmental Policy Act (NEPA) is as follows:

> *The effects, either additive or synergisitic, of past, present, and forseeable future activities within a planning area.*

In many land management agencies, such planning is conducted at the scale of whole basins. This becomes a logical boundary for analysis of cumulative watershed impacts.

Because watersheds are complex entities whose physical and biological functions are still poorly understood, this definition presents formidable challenges to resource specialists asked to assess such impacts. Project planners desire numerical results, but in many cases, even basic data are not available, and rarely is it in a format suitable for quantitative analysis. Consequently, there has been a tendency to rely upon generalized models which do not address the necessary range of potential impacts, and which also may be geographically inappropriate; or specialists have been directed to utilize professional opinion, usually without adequate knowledge of site-specific processes to substantiate such forecasting.

Within the resource agencies, there is increasing awareness of the inadequacy of many cumulative effects analysis (CEA) models. With issues such as increasing water demand, declining fish stocks, and continued loss of productive aquatic habitat, CEA's will continue to be an important aspect of public land management.

Elk River Watershed Cumulative Effects

In Elk River, high timber values are combined with important salmonid resources in a steep and erodible landscape. A majority of the watershed is managed by the Siskiyou National Forest. These holdings are located primarily in the upper parts of the basin, and comprise 79% of total basin acreage. The Siskiyou National Forest Land and Resource Management Plan calls for a substantial percentage of its 1990s allowable cut to be taken from the Elk River basin. Port Orford-cedar is found in the drainage and has recently sold for prices as high as $6,000 per mbf. The portion of the Elk within the National Forest also contains some of the most productive anadromous salmonid habitat on the Oregon coast (Reeves, 1988). Some 500,000 wild chinook salmon smolts and 14,000 wild steelhead smolts were produced in 1989 on about 18 miles and 33 miles of streams in Elk River respectively. It has been estimated that Elk River chinook provide up to $550,000 of net revenue annually to commercial fishermen, and the sport chinook fishery is valued at more than $350,000/year. High productivity is also combined with a diverse assemblage of salmonid species, including coho, chinook, and chum salmon, sea-run and resident cutthroat, resident rainbow trout, and winter steelhead trout. Elk River chum, coho, and anadromous cutthroat are currently being proposed for Federal sensitive stock listing (Nehlsen et al 1991). The basin is extremely prone to landslides, and past roading and timber harvest activities have severely impacted several tributaries; in general, however, these have primarily occurred outside of the most productive fisheries areas. A cumulative watershed effects analysis examining the impacts of past, current, and future activities in the Elk River was initiated in 1986 as part of the basin timber management plan.

We sought to produce an empirically-derived model which would provide a scientific basis for evaluating fisheries impacts from roading and timber harvest. In addition to the basin habitat and fisheries data, we also had information on landslide rates, geology, and water temperature trends. Forest Resource Geologist Cindy Ricks and I utilized these sources in formulating the analysis.

A quantitative assessment that addressed all potential impacts quickly proved to be too complex. Key hydrology data (precipitation measures, discharge, etc...) were also not available. We therefore had to focus on the impacts most relevant to the Elk River. To do this, we recognized that three key components had to be identified:

WHAT	would be causing the greatest impacts (source)
WHAT	would be impacted (impacts)
WHERE	would the impacts most likely occur (location)

Identification of source, impacts, and location set the framework for the Elk River cumulative effects analysis. Basin habitat and fish survey data were essential information used in the process.

Source

Timber harvest effects on hydrological regime, stream temperature, and fine or coarse sediment input were evaluated as potential impacts in the Elk River watershed. Of these, the effect of increased bedload input was selected for analysis. Monitoring indicated that coarse sediment delivered to streams from road and clear-cut-generated landslides (and the resulting aggradation of the channel) appeared to have had the most deleterious, pervasive impacts to salmonid habitat in the basin.

Data on landslide frequency and cause, slide volume, and proximity to the stream channel were used by Ricks to develop a harvest/roading landslide sediment delivery index (**LSDI**). LSDI represents a measure of the total amount of bedload sediment delivered to the stream channel from past road failures and timber harvest unit landslides. An LSDI value was calculated for each tributary in the National Forest portion of the Elk River.

Location

Although the upper Elk is typified by steep and narrow channels with high bedload transport capabilities, it also contains a number of low-gradient, wide valley floor reaches. The Reeves-PNW study found that these areas were also sites of highest fisheries productivity and species diversity. Because of their morphology, such locations are the most sensitive to excess bedload aggradation. We selected the low-gradient areas as analysis sites and labelled them as **critical reaches**. Past and future impacts to the critical reaches were portrayed in the analysis.

Impacts

Impacts on fish are often assessed as the effects on economically-important species. A more appropriate measure, however, may be to evaluate changes in fish community structure. Recent studies in the Pacific Northwest have suggested that changes in salmonid diversity may be a more sensitive indicator of land management impacts (Reeves 1992, draft). Activities such as logging or urban development appear to alter stream habitat characteristics, resulting in conditions that favors fewer species in the community. Fish with little economic value are overlooked in impact evaluations and are often lost from the assemblage. Habitat simplification has been suggested as one of the dominant mechanisms for loss of diversity.

A number of difficulties arise when attempting to predict forest management impacts on anadromous salmonids. Effects on fish population numbers are compounded by a host of factors outside the influence of timber harvest and roading. The relationship between logging and anadromous salmonids is more clearly focused by discussing how such activities result in physical changes to their habitat.

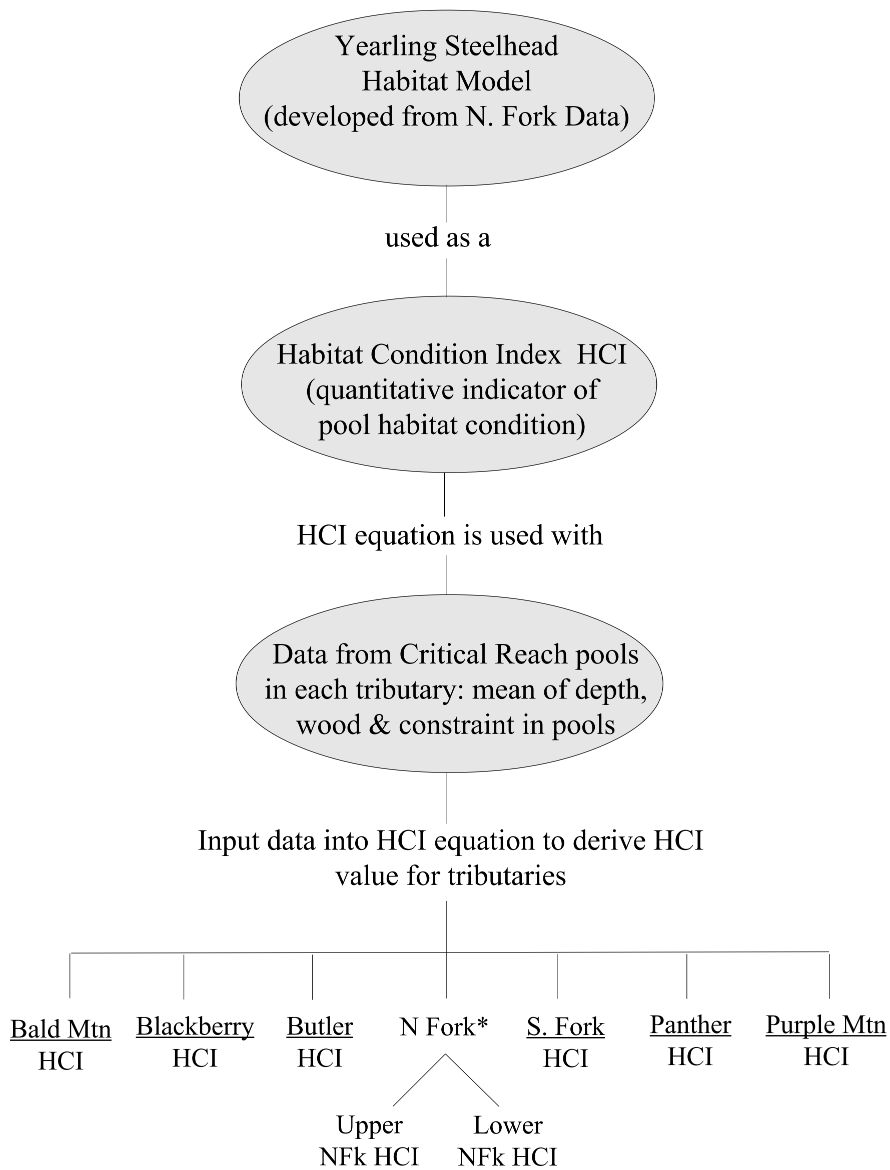
For Elk River, we utilized the community-level approach by identifying the specific effects of bedload on multi-species salmonid assemblages. This resulted in the selection of an indicator species that would represent salmonid community integrity. Effects on the current habitat condition for this indicator species was a key focus in the analysis.

Using the Steelhead Habitat Model and Basin Survey Data

The data indicated that pools in low-gradient reaches supported the greatest diversity of salmonids. Of primary concern in the Elk is the filling of such habitat by excess bedload. We utilized site-specific observations of microhabitat usage to determine which species would be most sensitive to depth loss. For low-gradient pools, observations of chinook, coho, steelhead fry/parr and cutthroat indicated that 1+ steelhead and cutthroat were associated with depth, primarily occupying the deepest portions of the pools near the substrata. Cutthroat trout and yearling steelhead were potential candidates for indicators; however, cutthroat were not well-represented in the data set (due to sampling problems). 1+ steelhead were thus selected as the community indicator species. Reeves (unpublished data) corroborates the relationship between loss of depth and disappearance of larger trout.

The yearling steelhead habitat model became a measure of the condition of pool habitat for yearling steelhead. In the model, increased numbers of these fish corresponded to greater depth, wood abundance, and increased valley floor width. The regression equation may therefore be viewed as a quantitative indicator of habitat condition that incorporates physical parameters known to be important for juvenile steelhead in the basin. For the effects analysis, the same equation was used as a yearling steelhead Habitat Condition Index (**HCI**).

Values from each tributary on **constraint**, **wood**, and **mean depth** were input into the HCI multiple regression equation to produce an HCI value for the sub-basin. Because we were interested in isolating impacts to low-gradient critical reaches, only data from such areas were used in these calculations. For determining the sub-basin HCI, values for the three variables represented mean estimates only from pools within the critical reaches (mean depth, mean wood, constraint at pools in low-gradient reaches). For analysis purposes and to simplify interpretation, all generated HCI values were proportionally adjusted to fit on a scale of zero to one. This process is summarized in the following flowchart:



A Comparison of Logging/Roading Sediment and Fish Habitat Condition:

The Cumulative Effects Model

Data on bedload sediment routing have not been collected for the Elk River. This represented an important missing link between landslide-delivered sediment and resulting effects on fish habitat downstream. Given that such information was not available, we tried to link timber harvest and road-generated bedload sediment (**LSDI**) with yearling steelhead habitat condition (**HCI**), at critical reaches via simple linear regression to develop a predictive model for bedload impacts. This incorporated basin-specific source, location, and impacts in the effects analysis.

To account for differences in bedload transport capability due to basin size, LSDI figures were divided by total basin acreage (LSDI/acre). In addition, only the LSDI from years 1964-1986 were used in the sediment calculations. This corresponds to the period when most of the logging and roading activities were conducted in the basin (this is relevant to the analysis, since LSDI is an estimate of only logging/roading bedload sediment). The time frame encompassed the period since the last major storm event in the Elk (1964 flood, 100 year+ re-occurrence interval). This was important because we assumed that the channel conditions represented in the HCI would also have to reflect the effects of the most recent major channel forming event.

In addition, the North Fork was separated into lower and upper sections for analysis, each with respective LSDI and HCI values. At present, upper basin sediment impacts appeared to have been limited to that portion of the watershed by the presence of an extensive storage reach/log jam complex. Although is expected that this sediment will eventually reach the lower basin, the division more accurately reflects the current condition for the sediment/fish correlation. This was the only basin where we could document such storage.

The results of the LSDI/acre and HCI comparison are shown in Figure 1 and formed the basis for our cumulative bedload effects "model". The graph shows a strong correlation between past landslide rates from harvest and roading, and the present condition of yearling steelhead habitat in each of the tributaries. Figure 1 shows the fit of a linear regression line on the data points (independent variable LSDI/ac transformed with an exponential factor to improve statistical fit, yielding a "curved" line). The equation for this regression line is the predictive model. While the linear equation yields a statistically adequate fit, the relationship is clearly non-linear and another line was fitted with STATGRAPHICS non-linear regression techniques (results not shown here).

Effects from proposed activities were evaluated by using the geology/landslide data base to develop a bedload sediment delivery model. This model would predict the volume of sediment delivered to stream channels by proposed roads and harvest units (<u>predicted LSDI</u>). For each tributary sub-basin, the LSDI/acre value was determined for planned activities in the 1990s decade. Predicted LSDI/acre was then input into the derived LSDI/HCI regression equation to generate <u>predicted HCI</u> values. These was then compared with current HCI to determine percent change in habitat condition. This gave an assessment of the impact from proposed logging.

Such comparisons showed potential negative impacts to two important salmonid tributaries (North Fork Elk River and Panther Creek basins). The North Fork was predicted to have as much as a 21% reduction in habitat condition. This prompted a major change in harvest plans for this basin. For the current timber sale, several of the proposed roads were eliminated, and boundaries on sale units were moved to eliminate entry into slide-prone areas. 1991 and 1994 sales were cancelled. The LSDI/HCI relationship was used to quantify the results of these alterations.

As indicated at the beginning of the paper, use of the effects analysis was subsequently discontinued by decision of Forest management staff. The ability

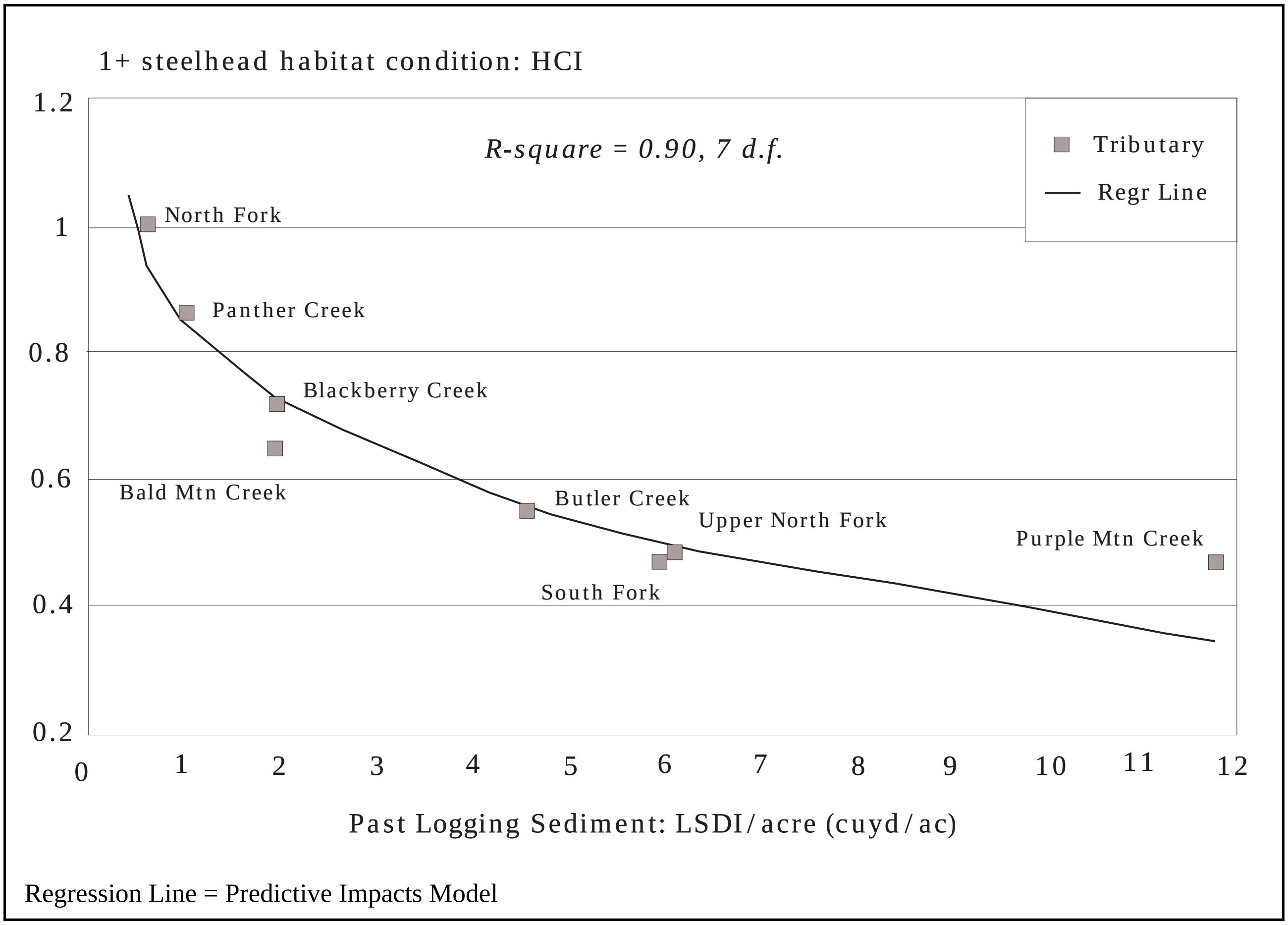


Figure 1. Elk River cumulative effects analysis comparison of past roading and harvest sediment and condition of habitat for yearling steelhead.

to link land management impacts to downstream fisheries is desired by managers, but their rejection of the approach outlined here suggests that the means to obtain such answers are still not satisfactory. Nevertheless, basin survey data will still provide critical information for watershed managers, and we are continuing to develop additional applications to better document timber harvest impacts.

Summary

Basin-wide fish habitat and population surveys provide a key source of information for managing fisheries resources. Important aspects include the wide variety of scales at which the data can be interpreted, the incorporation of statistical verification, and the direct link between physical habitat data and fish numbers. Two applications described here include species-specific habitat modelling and the linkage of management impacts to fish habitat. The latter has received considerable controversy, which underlines the continuing problems of quantitatively assessing watershed cumulative effects.

Acknowledgments

Data were generously provided by the Fish Habitat Research Group from the USDA Pacific Northwest Range and Experiment Station in Corvallis, Oregon. Dr. Gordon Reeves was particularly helpful both in making his Elk River data available, and in providing guidance on the effects analysis. I am also grateful to the reviewers of the draft for their extremely useful comments and criticisms.

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FHR Currents...Purpose

The Fish Habitat Relationship (FHR) Program of R-5 USFS has been established to research and develop information on fish ecology and to coordinate effective applications of this knowledge in managing and protecting our fisheries. By relating life stage requirements of specific species to physical habitat parameters, we are aiming at our main objective: developing a methodology to manage fisheries through the management of habitat.

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